THE OHIO STATE UNIVERSITY

Research Foundation
1960 Kenny Road
Columbus, OH 43210-1063

July 30, 1993

Defense Technical Information Center
Building 5, Cameron Station
Alexandria, Virginia 22304-6145

Dear Colleague:

Enclosed are 2 **copies of the report**

"Continuing Research on Friction and Wear of Materials"

prepared under Contract/Grant No. N00014-92-J-1608.

We have enjoyed working with you on this project and trust that this report is satisfactory. We look forward to the opportunity of working with you again in the future.

Sincerely,

Joy Ann Fischer

Joy Ann Fischer
Director, Editorial and Printing Services

This document has been approved for public release and sale; its distribution is unlimited.

MPN 769801

Date July 30, 1993

RF Project No. 726020

Type of Report Fiscal Year

Shipped By Certified/Return Receipt

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Rigney/Rundle - RF

FY92 End of Fiscal Year Letter
(01 Oct 1991 - 30 Sep 1992)

ONR CONTRACT INFORMATION

Contract Title: Continuing Research on Friction and Wear of Materials

Performing Organization: The Ohio State University

Principal Investigator: D. A. Rigney

Contract Number: N00014-92-J-1608

R & T Project Number: pri 6014-05

ONR Scientific Officer: P. P. Schmidt, ONR Code 3312

Enclosure (1)

FISCAL YEAR REPORT

on

CONTINUING RESEARCH ON FRICTION AND WEAR OF MATERIALS

to

The Office of Naval Research

July 26, 1993

D. A. Rigney
Materials Science and Engineering
The Ohio State University
116 West 19th Avenue
Columbus, OH 43210-1179

A. DESCRIPTION OF THE RESEARCH GOALS AND APPROACH

This project was designed to provide new information on the effects of ion implantation on surface (adhesion) and subsurface (deformation) effects during unlubricated sliding of metals. The base materials are copper and iron, and the implanted species are also copper and iron. Thus, in some samples there should only be structural changes caused by implantation (e.g., Fe into Fe, Cu into Cu), while in others there will be composition changes as well (e.g., Cu into Fe, Fe into Cu). Copper and iron were chosen because of the considerable amount of literature available for comparison of results from testing of these metals. Also, their hardness values and deformation behavior are different, the OSU group has experience with both metals, and the phenomenon of selective transfer, extensively studied in the former USSR, usually involves both Cu and Fe.

The project was originally designed to address questions raised at a workshop at Argonne National Laboratory in 1988 (1), in particular questions associated with separating surface and subsurface effects. Recognizing that these may interact in ways which make them difficult to separate, we have attempted to use ion implantation of samples tested in vacuum in a pin/disk sliding system. Because geometric effects are known to be important, we are using both Cu/Fe and Fe/Cu configurations (pin/disk). There are thus 36 different combinations of pin/disk for each implanted thickness used, because each component can be Cu, Fe, Cu(Cu), Fe(Fe), Cu(Fe) or Fe(Cu), where the species in parentheses is the implanted species.

B. PROGRESS AND SIGNIFICANT RESULTS IN THE PAST YEAR

The graduate student working on this project passed her General Examination during Winter Quarter, 1991. Since then, she has been working full-time on her research. She has had to surmount a number of difficult problems which slowed initial progress. For example, the first set of implanted specimens was contaminated with unacceptable amounts of carbon and cadmium. The student found that the source of the carbon contamination was the furnace used earlier for annealing the specimens. She also traced the Cd contamination to plated screws used in the implantation chamber at Mound Laboratories. Another problem involved silicon contamination during preliminary sliding tests. The student traced this to the diffusion pump oil and the vacuum grease used in the vacuum system. We therefore changed to a different pin/disk device enclosed in a cleaner vacuum system which is pumped by a turbomolecular pump. At the same time, disk shaped pins were replaced by hemispherical pins which provide before reproducibility of the contact geometry, especially at small sliding distances. The student also discovered that the balls purchased to be used for the Cu pins contained embedded SiC particles, making them unuseable without further surface preparation. The problem here is the ease of embeddability of hard particles in the soft copper. Therefore, rather than use standard metallographic polishing to remove the SiC, we used chemical polishing. This created some waviness but provided a smooth surface uncontaminated with hard particles. Other problems involved electrical noise in the friction measuring system. Changes in grounding and shielding greatly reduced this problem. All of these problems were identified and solved by the student herself.

By far the most serious problem has been the delay in obtaining implanted specimens from Mound Laboratories, Miamisburg, OH. Soon after the problem with Cd contamination was solved, it was announced that Mound Laboratory would shut down, as casualty of the nations budget problems and changes in the world related to the collapse of the former USSR. The person doing our implantatios was reassigned to paperwork associated with the clean-up and shut-down of the Labs. We scrambled to find an alternative source which would not charge a large amount for the service. The project budget had been planned with donated implantation services, because Mound Labs personnel had agreed earlier to do this work for us without charge. Personnel at Oak Ridge National Laboratory agreed to help. However, due to differences in equipment and laboratory policy, that would require months of our being present at Oak Ridge, with associated unbudgeted costs. At the end of this reporting period, we still had not solved this problem, and we had not received implanted specimens suitable for testing for this project. [Note: A few months later, at beginning of 1993, Mound Labs personnel agreed to start up their implantation equipment again and implant our samples. Sliding tests then proceeded during 1993. The results will be described in the next fiscal year report.].

A delay of nearly a year was caused by the several factors listed above, particularly the delay in obtaining suitably implanted test specimens. However, the student did not waste that time. She became proficient with several scanning and transmission electron microscopes and with specimen preparation for those instruments. She has also reviewed the literature systematically and she has written a section of her thesis based on that review.

Two series of samples are being implanted. These use different accelerating voltages and fluences to give different implantation depths and concentration profiles. For example, Fe is implanted with Cu at 5 keV and a fluence of 2x1015 Cu+/cm2, giving a calculated concentration peak depth of about 2.6 nm and a concentration of about 5 at. %. For a thicker modified region, higher implantation energy is used. In that case, a more uniform layer is created by using multiple implantations: 2x1016 Cu+/cm2 at 200 keV, 3x1015 Cu+/cm2 at 60 keV and 3.5x1015 Cu+/cm2 at 35keV, giving a peak depth of about 100 nm and a maximum concentration of about 8 at. % Cu. These calculated values will be checked by using Auger electron spectroscopy combined with sputter profiling, as well as profilometry of the sputter crater.

C. RESEARCH PLANS FOR THE NEXT FISCAL YEAR

1. Implanted specimens received from Mound Laboratories will be tested in vacuum, using both short and long sliding distances. This will allow checking behavior before and after any mild to severe transition which may appear.

2. If the 50 g load being used for preliminary tests is too large, we will reduce this by at least ten times. If the friction in the journal bearings of the present pin/disk system is too large to be used with smaller loads, we will replace it with a system using ball bearing mounts. [Note: This was found to be necessary in the following reporting period.]

3. Nanohardness measurements on both implanted and unimplanted specimens will be made. Correlations with the Hd/Hp ratio of Kato can then be attempted (2). Also, it can then be determined if the sign of the hardness gradient at the surface affects the sliding behavior. With hardness and hardness gradient data available, the energy-based model of Heilmann can be applied (3).

Report References:

1. Workshop on Wear Modeling, Argonne National Laboratory, Argonne Laboratory, Argonne, IL, June 16-17, 1988.

2. K. Hokkirigawa and K. Kato, Tribol. Int. 21(1388)51-57.

3. P. Heilmann and D. A. Rigney, An Energy Based Model of Friction and Its Application to Coated Systems, Wear 72(1981) 195-217.

D. LIST OF PUBLICATIONS/REPORTS/PRESENTATIONS

1. Papers Published in Refereed Journals

S. Venkatesan and D. A. Rigney, Sliding Friction and Wear of Plain Carbon Steels in Air and Vacuum, invited for special volume of Wear 153(1992)163-178.

S. M. Kuo and D. A. Rigney, Sliding Behavior of Aluminum, Materials Sci. and Engin., A157(1992)131-143.

D. A. Rigney, The Role of Characterization in Understanding Debris Generation, in Wear Particles, Proceedings, 18th Leeds/Lyon Symposium, Lyon, France, eds. D. Dowson et al., pp. 405-412, 1992.

D. A. Rigney, R. Divakar and S. M. Kuo, Deformation Substructures Associated with Large Plastic Strains, invited for Viewpoint Set by N. Hansen, Scripta Met. et Mat. 27 (1992)975-980.

2. Non-Refereed Publications and Published Technical Reports

none

3. Presentations

a. Invited

D. A. Rigney, First Plenary Lecture, The Roles of Hardness in the Sliding Behavior of Materials, Int'l. Conf. on New Materials and Technologies in Tribology, Minsk, Belarus, Oct. 6-9, 1992.

b. Contributed

none

4. Books (and sections thereof)

D. A. Rigney, The Role of Characterization in Understanding Debris Generation, in Wear Particles, Proceedings, 18th Leeds/Lyon Symposium, Lyon, France, eds. D. Dowson et al., pp. 405-412, 1992.

E. LIST OF HONORS/AWARDS

Name of Person Receiving Award	Recipient's Institution	Name, Sponsor and Purpose of Award
D. A. Rigney	The Ohio State U.	First Plenary Lecture Int'l. Conf. on New Mat'ls. and Technologies in Tribology, Minsk, Belarus, Oct. 6-9, 1992.

Enclosure (3)

F. PARTICIPANTS AND THEIR STATUS

1. Dr. D. A. Rigney, Professor, Materials Science and Engineering, The Ohio State University, Project P.I.

2. L. H. Zhang, Graduate Research Assistant, Ph.D. candidate; passed General Examination for candidacy for Ph.D.--working full-time on this project. Expected date of receiving degree: 12/93.

G. OTHER SPONSORED RESEARCH DURING FY92

1. D. A. Rigney, Selective Transfer in Tribology, NSF, Engineering Division (Surface Engineering and Tribology), SGER program, $35,000, 7/1/91-9/14/93, for one graduate student.

2. D. E. Kim and D. A. Rigney, Surface Modification for Controlling Friction and Wear, OSU-CMR (Center for Materials Research) sponsored project, Office of Research, The Ohio State University, $44,044, Jan 1, 1992-June 30, 1993, for one graduate student in MSE Dept. and one in Mech. E. Dept.

H. SUMMARY OF FY92 PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/PARTICIPANTS (Number Only)

		ONR	non ONR
a.	Number of Papers Submitted to Referred Journal but not yet published:	0	0
b.	Number of Papers Published in Refereed Journals:	2	2
c.	Number of Books or Chapters Submitted but not yet Published:	0	0
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i.	Number of Contributed Presentations at Workshops or Prof. Society Meetings:	0	0
j.	Honors/Awards/Prizes for Contract/Grant Employees: (selected list attached)	1	0
k.	Number of Graduate Students and Post-Docs Supported at least 25% this year on contract grant:	1	2
	Grad Students: TOTAL	1	2
	Female	1	0
	Minority	1	0
	Post Doc: TOTAL	0	0
	Female	0	0
	Minority	0	0
l.	Number of Female or Minority PIs or CO-PIs		
	New Female	0	0
	Continuing Female	0	0
	New Minority	0	0
	Continuing Minority	0	1

ONR FOREIGN TRAVEL POLICY

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(01 Oct 1991 - 30 Sep 1992)

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	Grad Students: TOTAL	1	2
	Female	1	0
	Minority	1	0
	Post Doc: TOTAL	0	0
	Female	0	0
	Minority	0	0
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	New Female	0	0
	Continuing Female	0	0
	New Minority	0	0
	Continuing Minority	0	1